VARIABLE-THRUST MEMS COLLOIDAL THRUSTER

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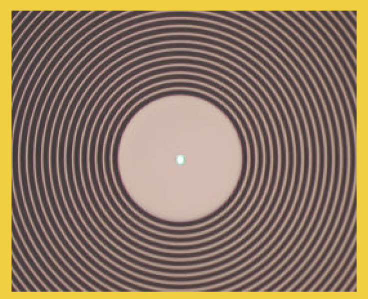
Colloidal thrusters are electric propulsion devices that accelerate charged liquid droplets to produce thrust. Novel Micro-Electro-Mechanical System (MEMS) fabrication techniques have provided the technology to design a thruster with the efficiency, precision, and throttle-ability necessary for spacecraft propulsion systems and precise position control. Current research focuses on laboratory up, thruster fabrication, and experimental testing.

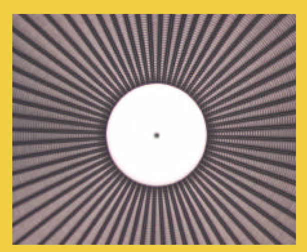
Fabrication

Array of thrusters on silicon wafer

The wafers are fabricated from 300 μm double sided and polished silicon wafers.

The silicon is etched using reactive ion etching (RIE) and oxidized to obtain a layer of silicon dioxide (SiO2).





(above) Radial die

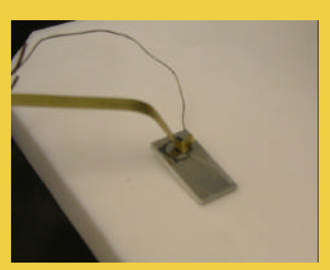
(right) Spanner die

Photoresist is used to pattern the wafers, and deep reactive ion etching (DRIE) is used to etch the SiO_2 to a depth of 70 μm. Through-holes are etched using a similar method.

Wafer is placed in wet oxidation.

The wafer is protected with photoresist, diced, and then catalogued for use.

Diced wafers

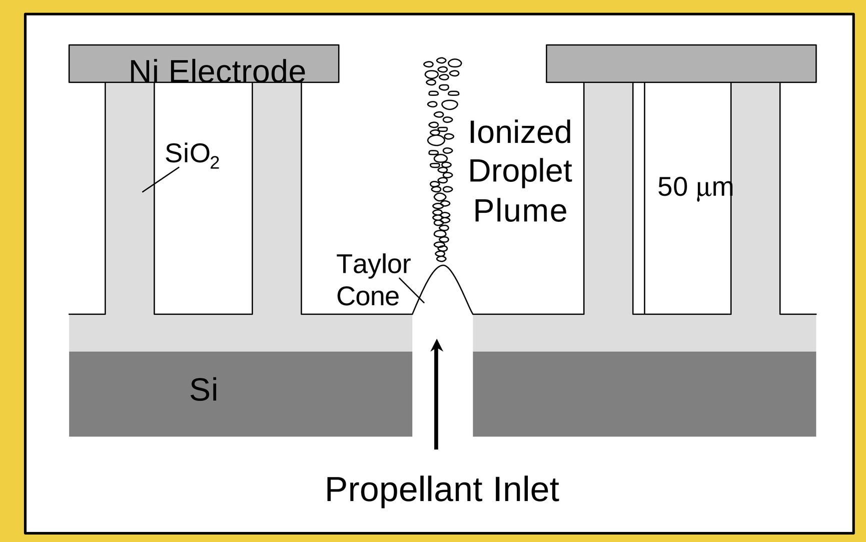


Insulation breakdown tests were performed on the die using various methods of attachment.

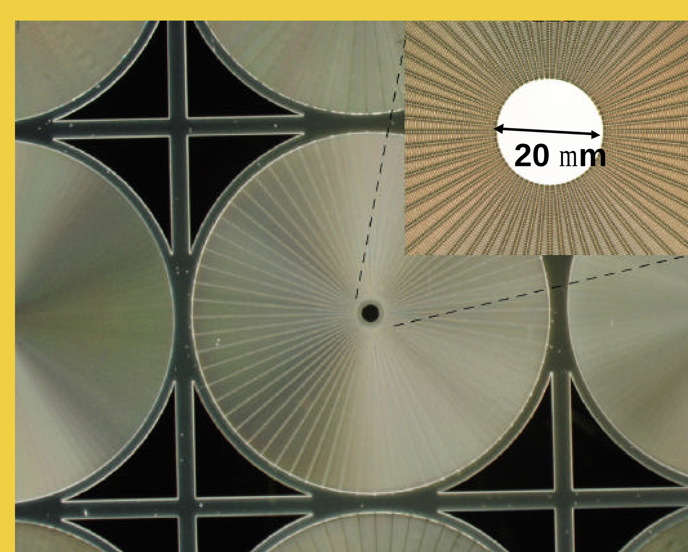
To attach the propellant tube to the die, several methods are being investigated.

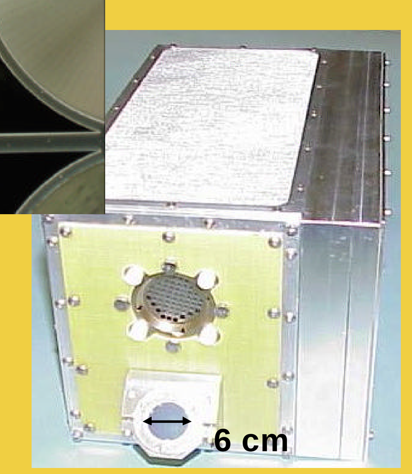
Colloidal Thruster Design and Theory

- Each thruster is composed of conductive ionic solution (formamide + NaI) supplied to an emitter electrode via a tube (traditionally a hypodermic needle). An extractor electrode is placed a short distance from the emitter electrode.
- Voltage is applied across the two electrodes to induce an electric field on the order of 10^6 V/m. This electric potential draws the liquid propellant out toward the electrode.
- At the emitter, the conductive liquid solution forms a characteristic cone shape due to the opposition between the electric field and the liquid surface tension. This cone is referred to as the Taylor cone.
- The Taylor cone breaks down at the critical cone diameter due to fluid instability and an excessive electric field potential on the surface of the liquid.
- Thrust is produced by the acceleration of these droplets.



Schematic of MEMS Colloidal Thruster





(above) Close-up of thruster emitter on MEMS device

(right) Macro-scale device

Why use Micro-Electro-Mechanical Systems (MEMS)?

✓ large numbers of arrays to be produced more rapidly at less cost
✓ greater emitter density expands thrust range to increase throttle-ability
✓ smaller dimensions reduce voltages necessary for operation

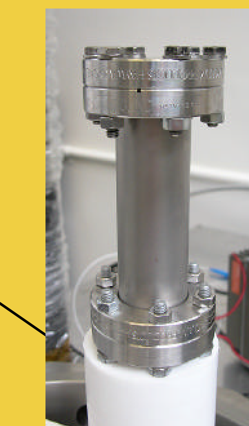
Additionally, variable thrust capabilities would allow:
✓ reduced mass by using one thruster for several maneuvers
✓ requires less propellant than a regular thruster

Performance Parameters

Thrust: 1 μN – 100 mN
Isp: 500 -10,000 s

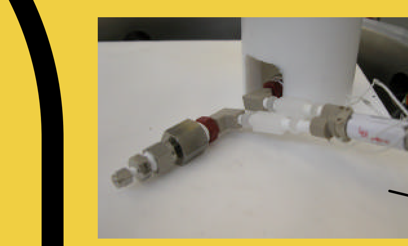
Experimental Set-Up

Static voltage applied to electrodes using Bertram power supply (negative) and an EMCO power supply (positive)

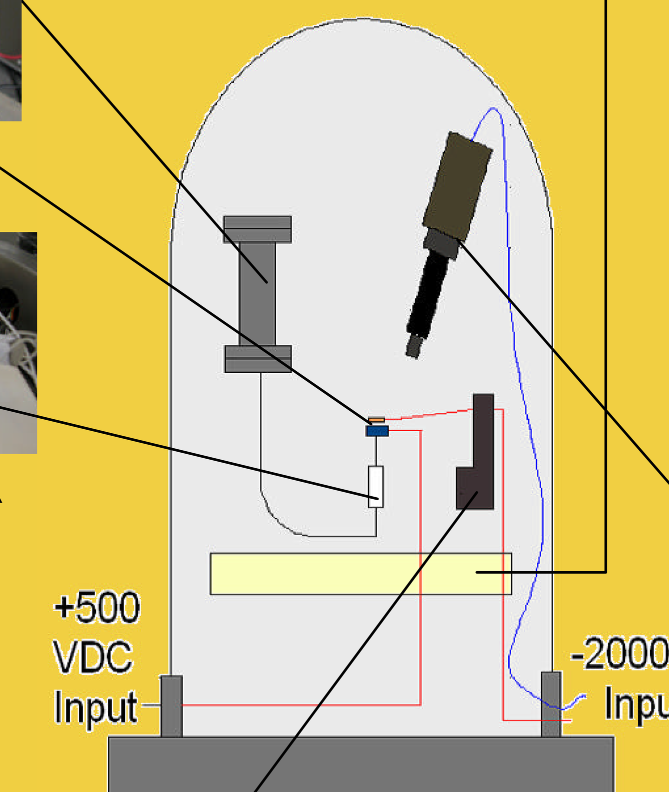


◀ Propellant tank is composed of a vacuum flange and pressurized using ambient air pressure.

Hardware is insulated from the stand through mounting on a 1.25 cm thick Teflon plate.

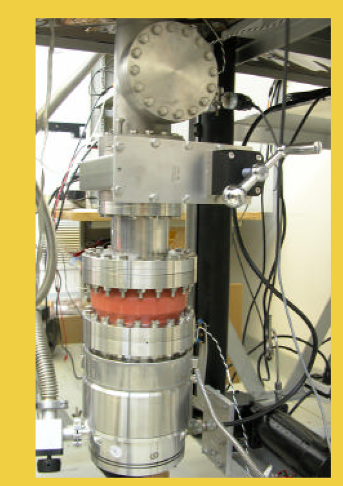


Propellant is delivered via a Lee micro-valve. ▲

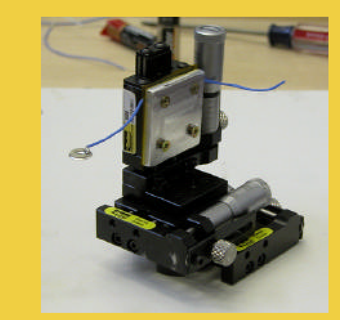


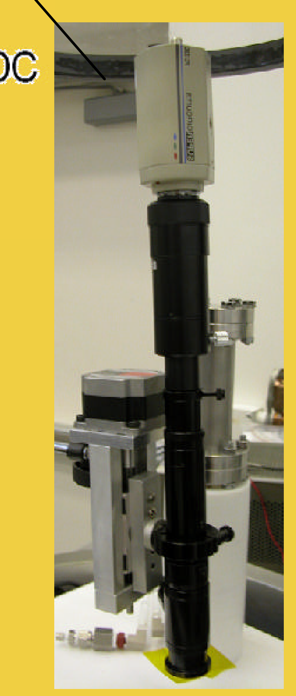
▲ Testing is being completed in a glass bell jar at pressures on the order of 10^{-6} Torr. A silicon wafer is shown in the foreground.

Three-axis translation stage will provide ease of movement in alignment of extractor electrode.



Turbopump to obtain pressures from 10^{-3} to 10^{-7} Torr ◀





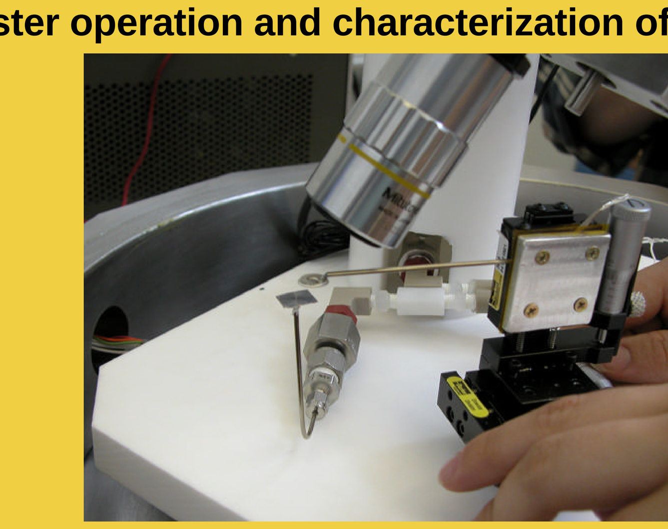
◀ Mitutoyo microscope and high-resolution black and white 2/3" charged-coupled device (CCD) camera. System is mounted on an base stand connected to the Teflon plate. Vacuum-rated Velmex positioning stage provides microscope focus with changing tank pressures

Progress / Future Work

- ❑ **Complete laboratory set-up and component testing**
- ❑ **Thruster operation and characterization of the Taylor cone**

✓ Develop design for MEMS colloidal thruster array: throttle-able, new insulation techniques

✓ Thruster array fabrication on silicon wafer



- ❑ **Demonstration of throttling**
- ❑ **Complete Time-of-Flight (TOF) experiment to measure droplet velocity**
- ❑ **Test complete array of thrusters and verify performance data**

Acknowledgements

➢Kansas Space Grant Consortium
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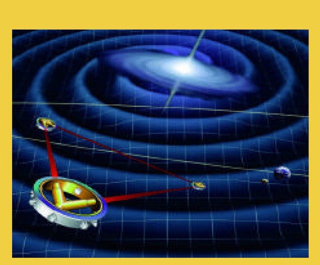
➢NASA Academy Program

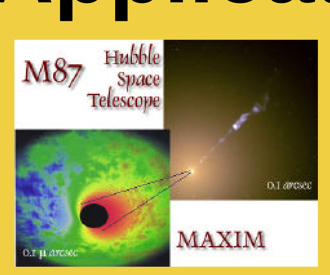
Applications

✓Attitude control / Formation flying missions: 1 -100 mN

Laser Interferometer Space Antenna (LISA) ▶



Terrestrial Planet Finder (TPF) ▶



◀ Micro-Arc Second X-Ray Imaging Mission (MAXIM)

✓ Precision attitude control / Disturbance compensation systems (providing essentially "drag-free" flying capabilities to negate any residual solar or atmospheric forces): 1 – 100 μN

Gravity Probe B Mission ◀